

# Molecular Electronics (Moletronics)

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# Moletronics – What's It All About?

*Replace conventional components with  
self-assembled functional molecules*

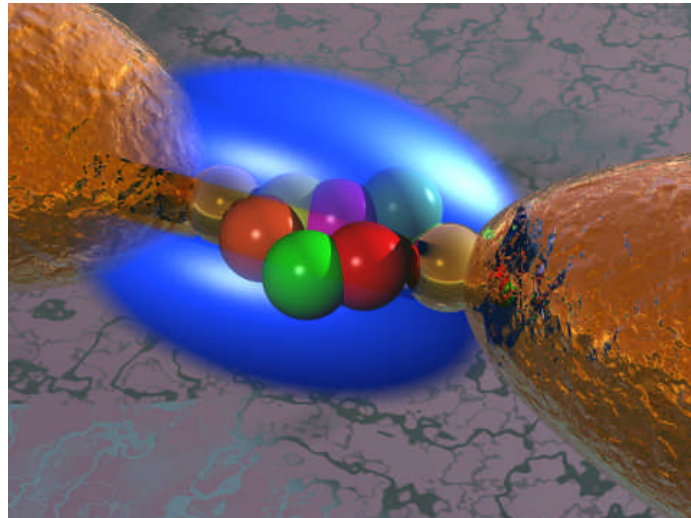
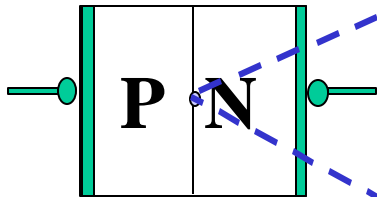
P-N Diode

90,000 nm<sup>2</sup>



Molecule

9 nm<sup>2</sup>



# Information Content

- One color photo  $\sim 10^5$  b
- Average book  $\sim 10^6$  b
- Genetic code  $\sim 10^{10}$  b
- Human brain  $\sim 10^{13}$  b
- Annual newspapers  $\sim 10^{14}$  b
- Library of Congress  $\sim 10^{15}$  b
- Human culture  $\sim 10^{16}$  b
- Annual television  $\sim 10^{18}$  b

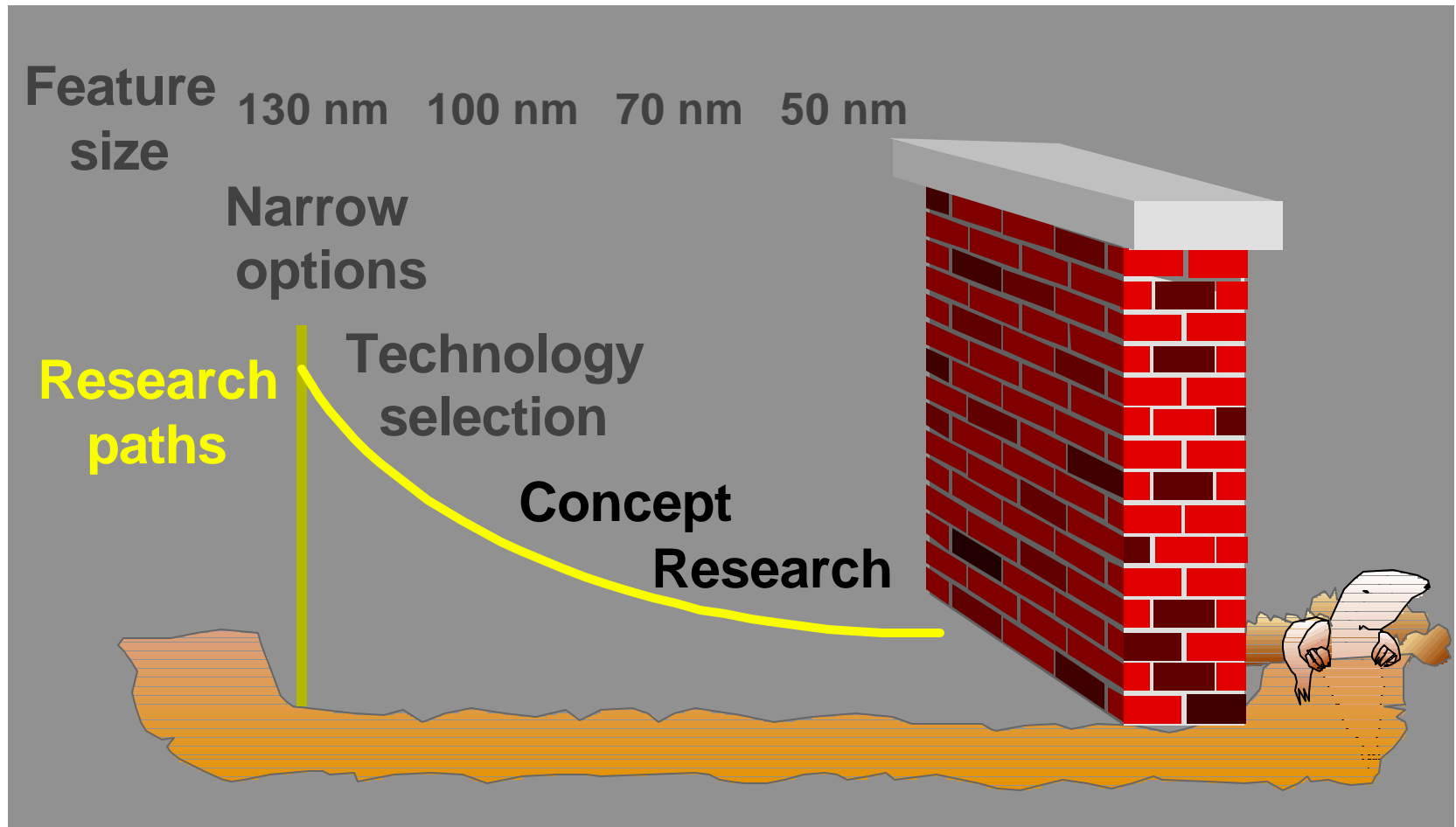
**Total  $\sim 10^{20}$  bytes**

Imagine if we had a mole ( $> 10^{23}$ ) of bytes!!



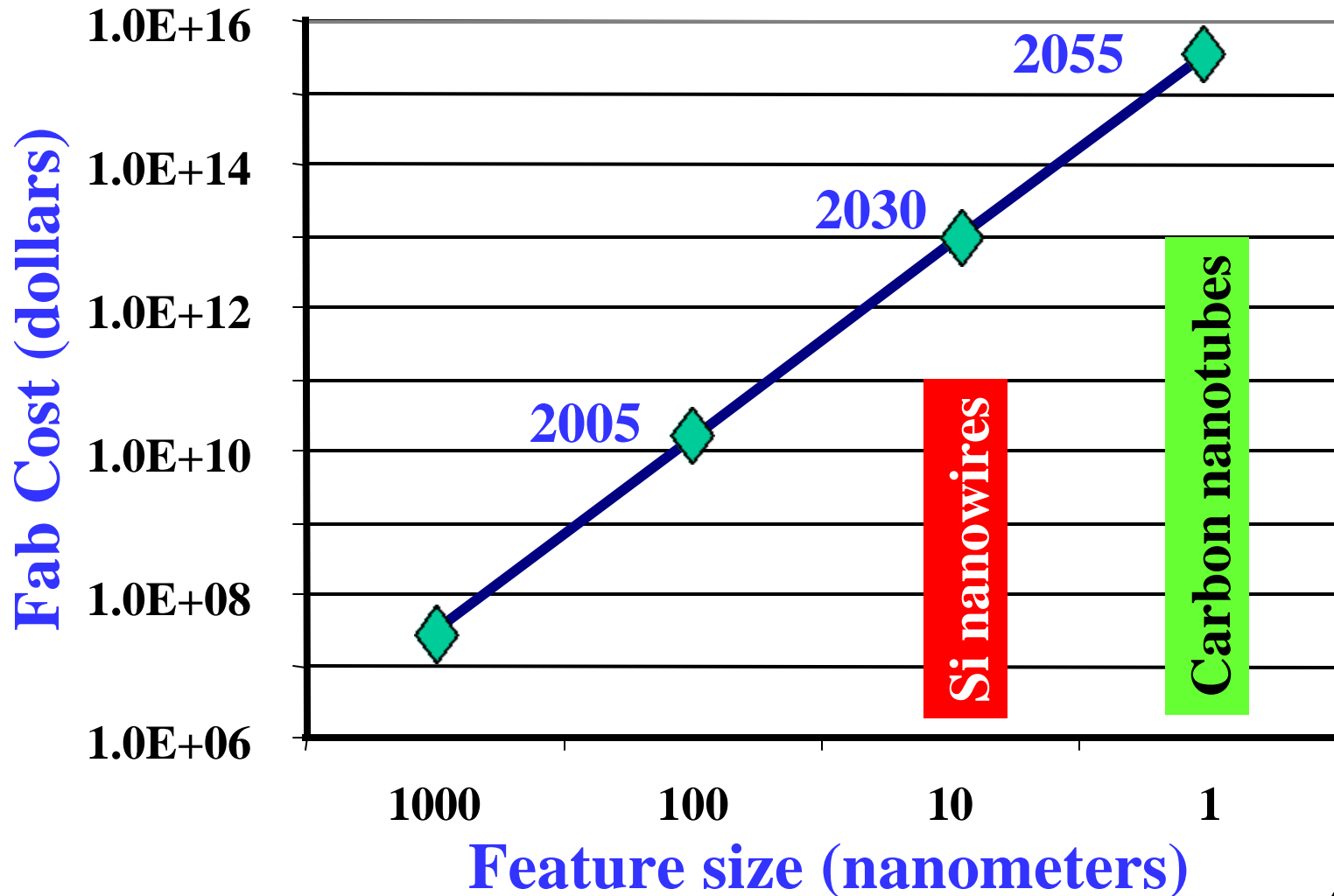
# Moletronics – An Underground Operation

*Technical hurdles for “slice and dice” Si CMOS*



# Moletronics Overcomes Fabrication Costs for Lilliputian Computers

*Moore's First Law vs. Moore's Second Law*

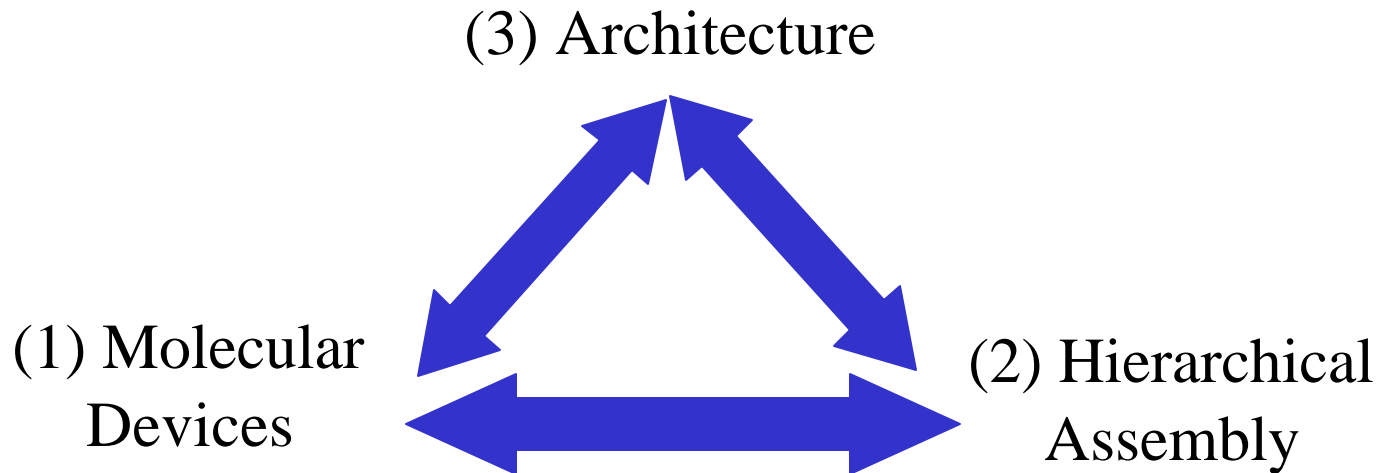


# Moletronics: Re-Inventing the IC at Molecular Densities

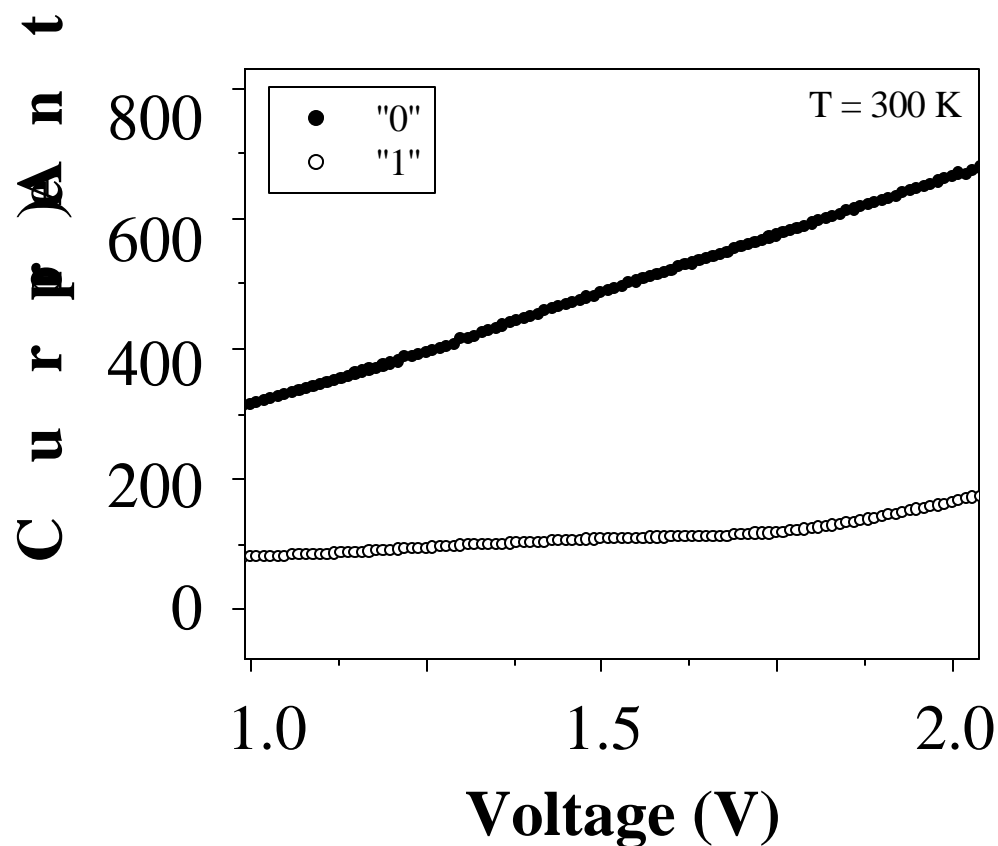
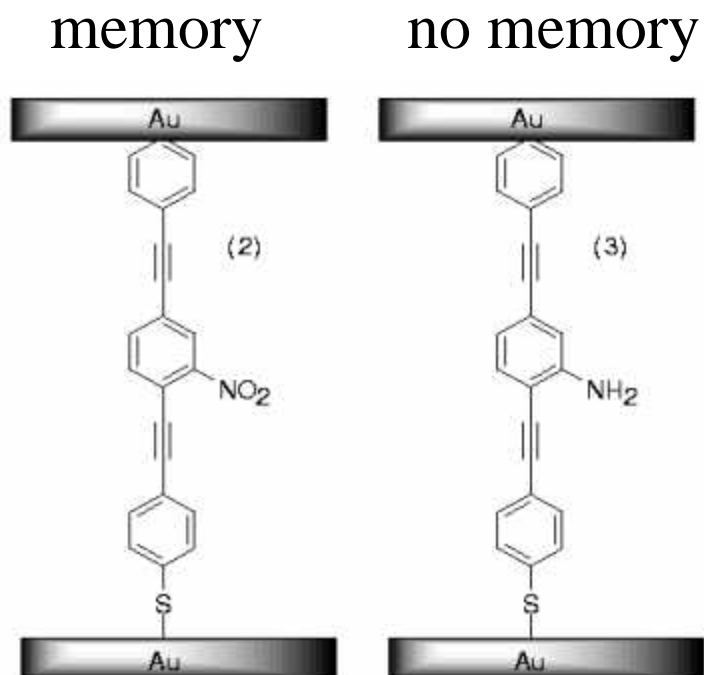
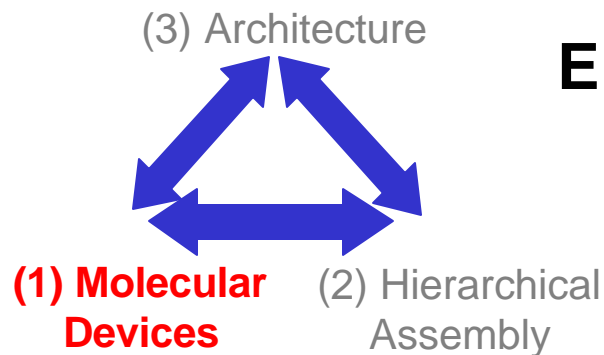
- **Goal**

- Demonstrate computational functionality and I/O in *scalable* molecular systems using hierarchical assembly at insanely high device densities

- **Moletronics Approach**

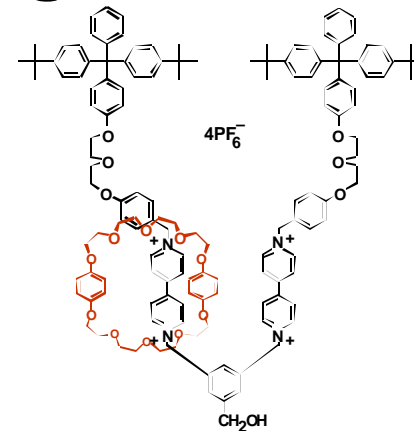
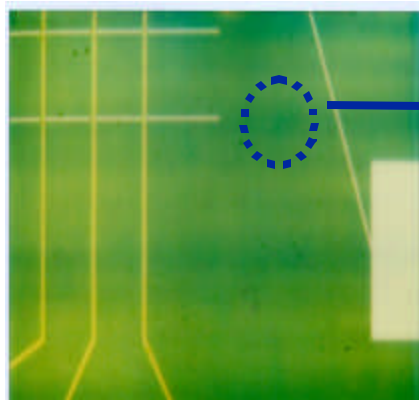


# The Need to Chemically Design Electronic Functionality

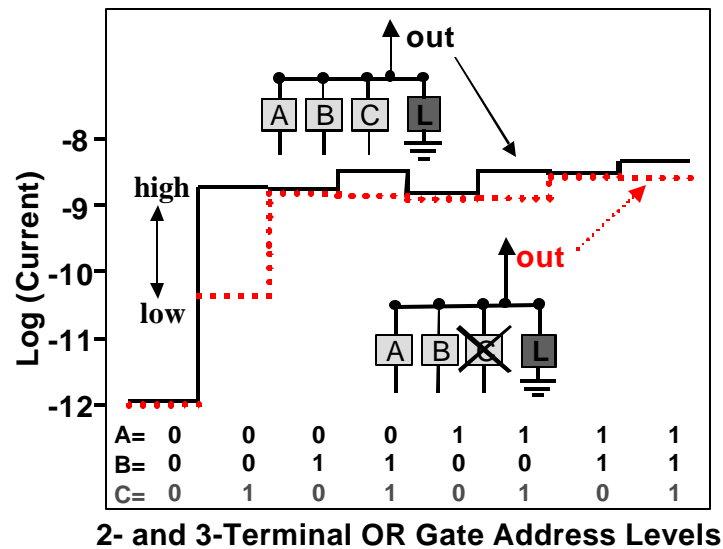


*Yale University, Rice University*

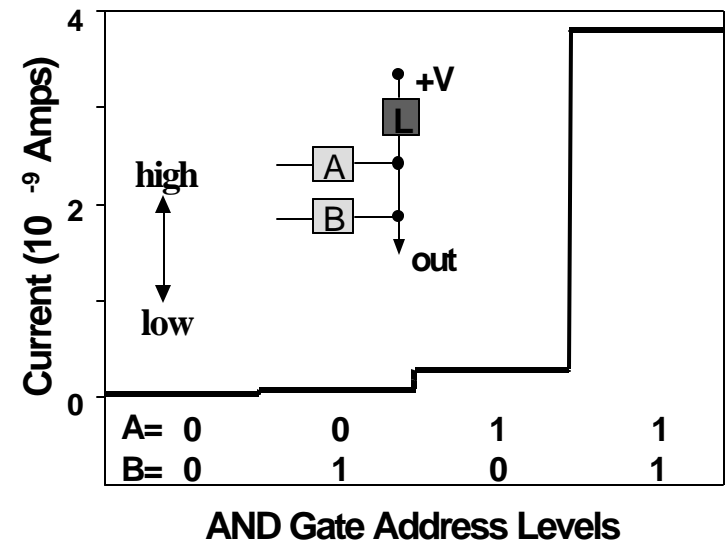
# “OR” and “AND” Gates Have Been Fabricated Using Molecules



## Moletronic OR Gate

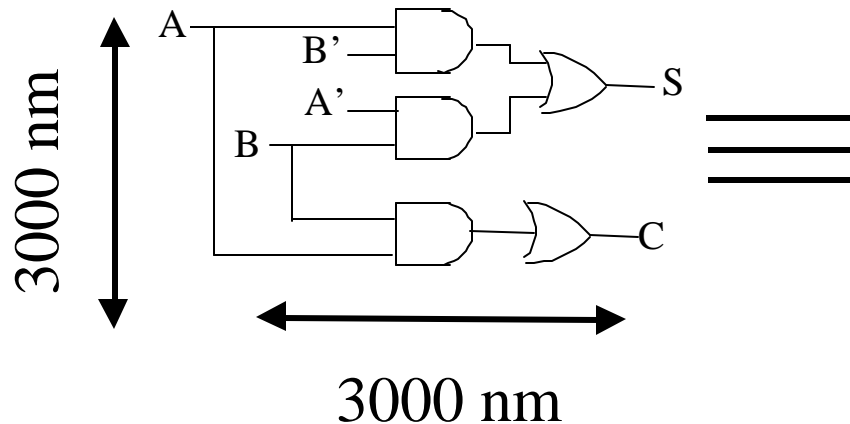


## Moletronic 2-Input AND Gate



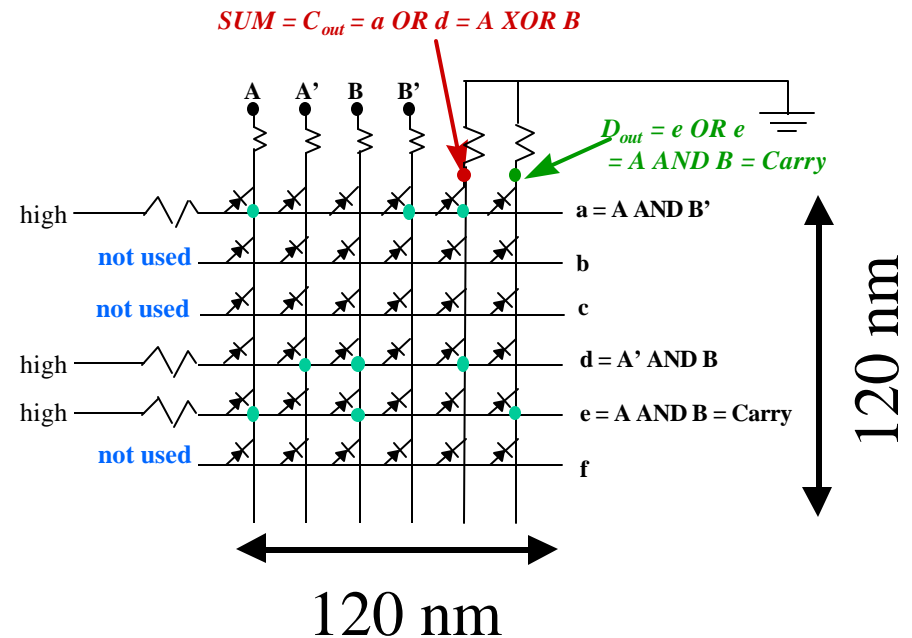
# Mountains Into Molehills

*Conventional Si*



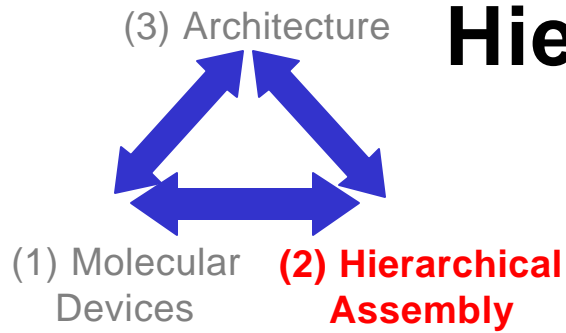
Logic gates ~ 3 transistors

*Moletronics*



10 nm lines, 20 nm pitch

# Hierarchical Assembly

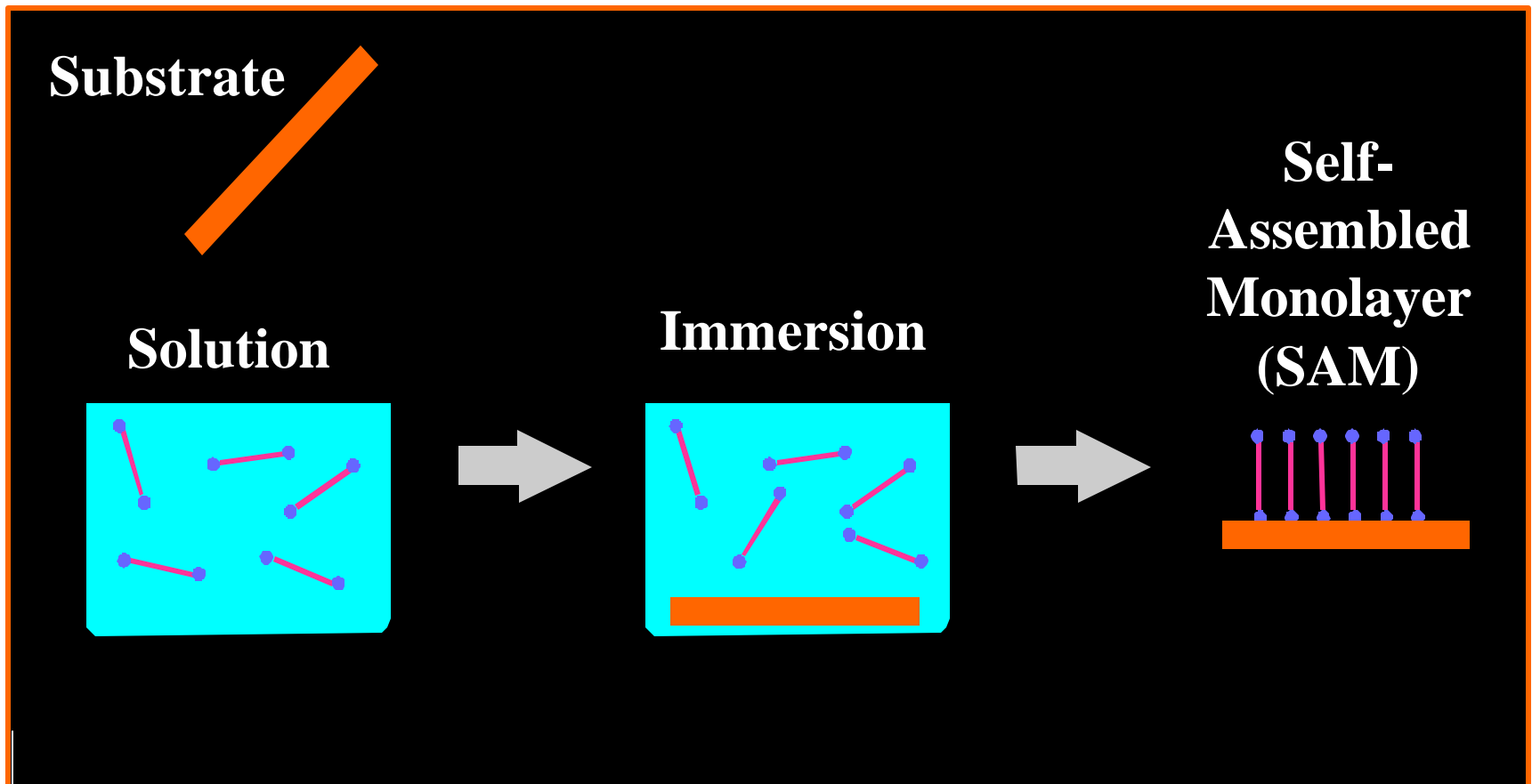


## Crossing the Chasm from the Nano to the Micro-World



# Self-Assembly

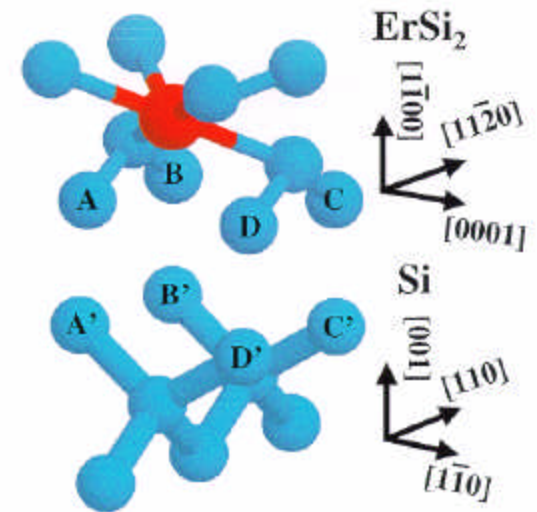
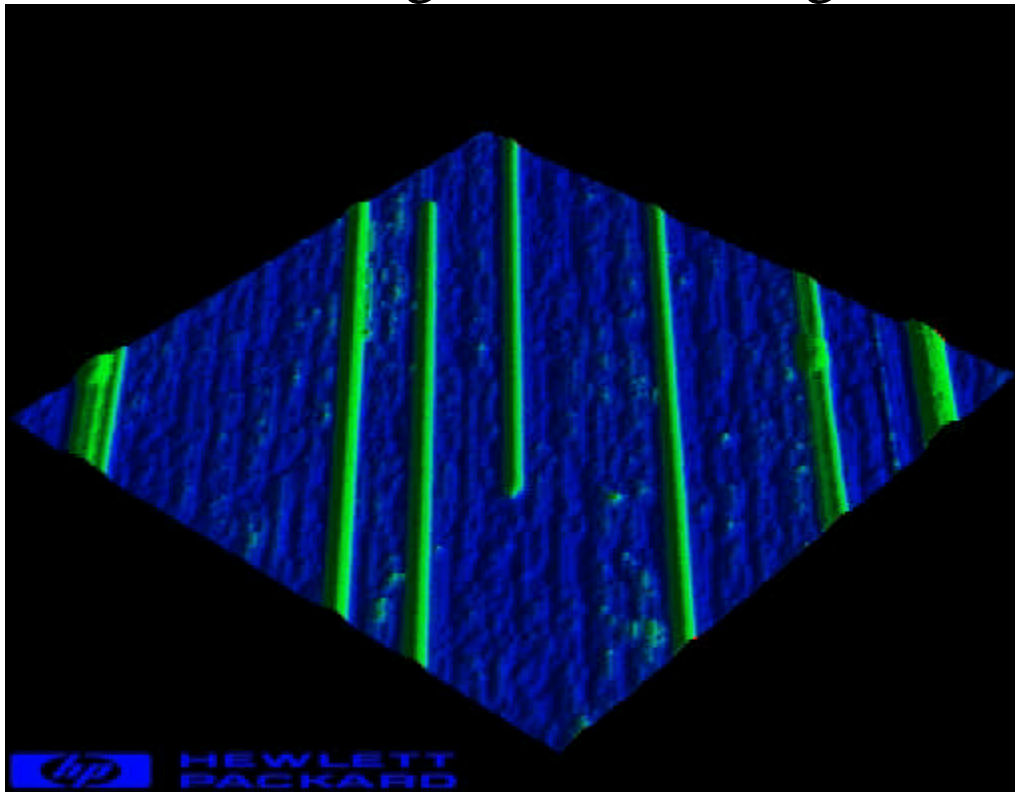
*Process in which structures naturally assemble into desired patterns based on thermodynamic equilibrium*



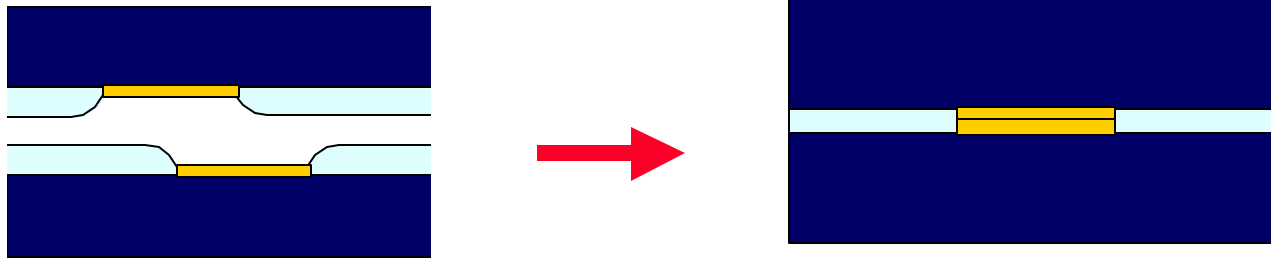
# Self-Assembly Makes Aligned Arrays of 2 nm Nano-Wires

Assembly dictated by anisotropic lattice mismatch with Si

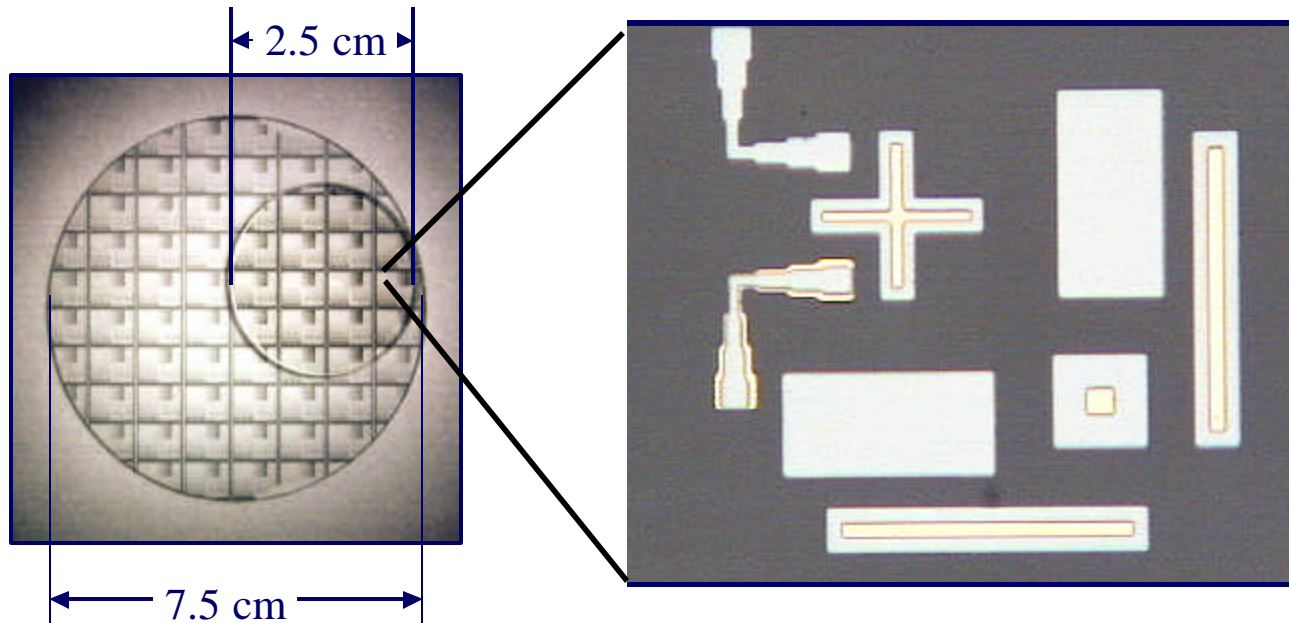
Unbelievable – 10 atoms wide,  
2 atoms high, microns long!



# Assembly of Cross-Bars Using Water (Hydrophobic/Hydrophilic Interactions)

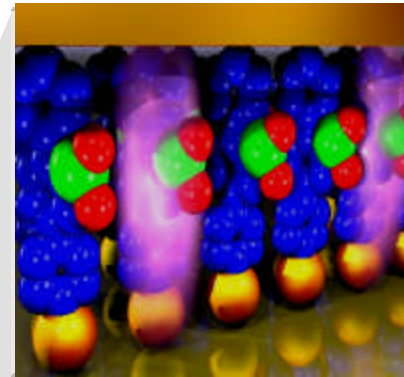


- Chip border used as primary driving force for alignment
- Better than 1  $\mu\text{m}$  alignment achieved across a 2.5 cm substrate
- Local alignment anticipated to be at least 10's of nm

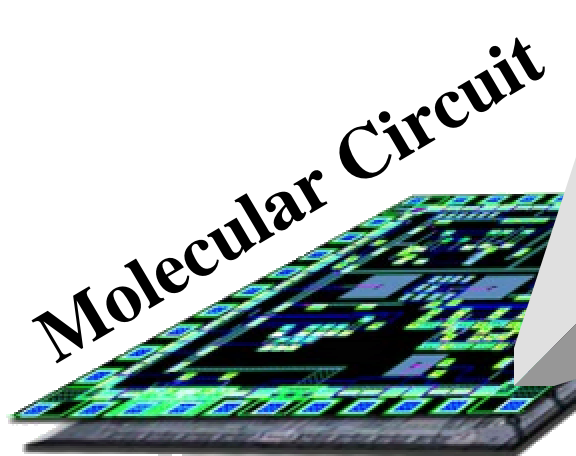
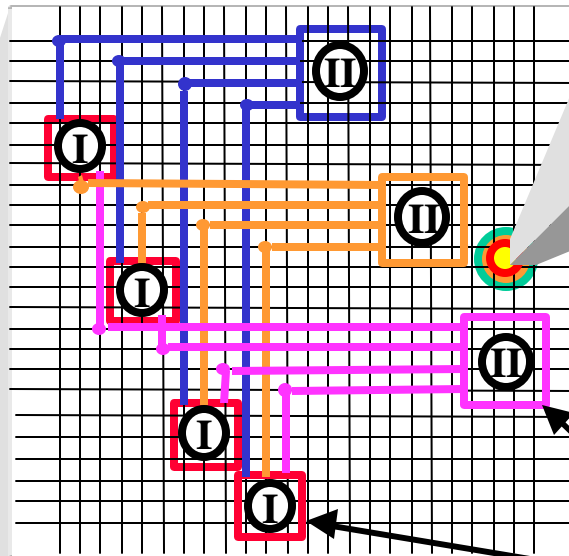


# Hierarchical Assembly

**Molecular  
Devices**



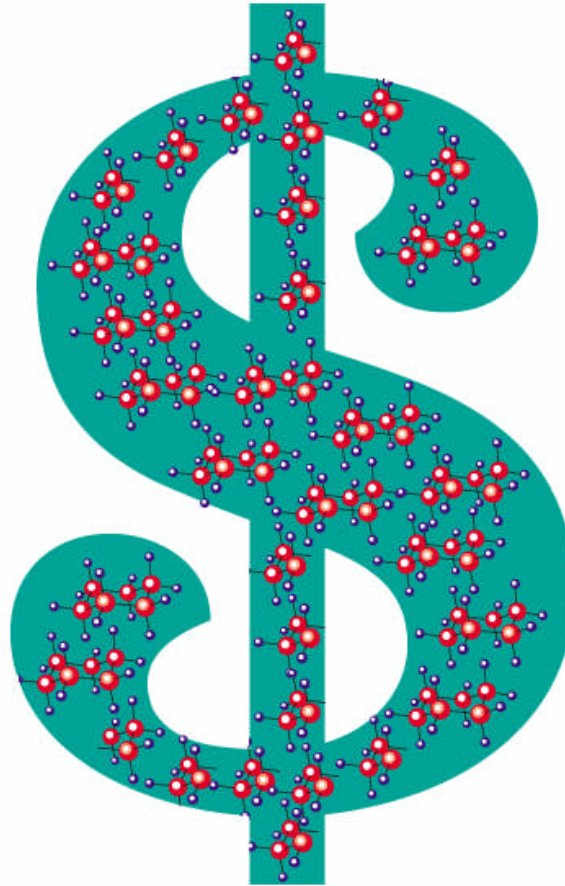
**Electronic Module**



**Nanoblocks**



# Moletronics Objective

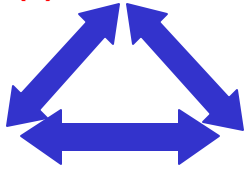


Hierarchical-Assembly Will Reduce The Cost  
of Electronics Manufacturing



(3) Architecture

# Architecture and Defects



(1) Molecular Devices

(2) Hierarchical Assembly

When a single defect  
could kill 'ya



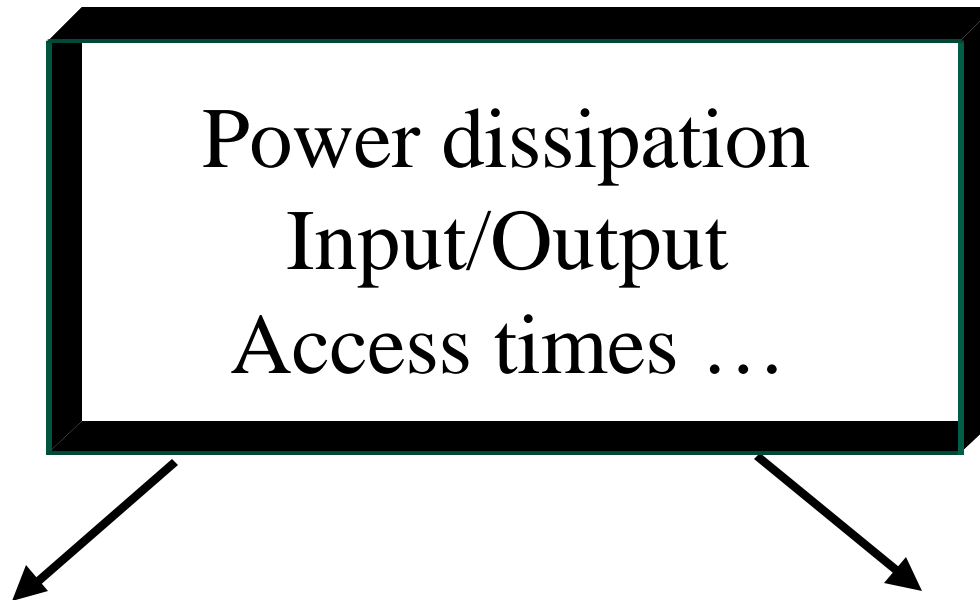
When defects won't  
kill 'ya



- Scalable Architectures
- Defect tolerance
- Algorithm development



# System Architecture Scalability



## Supercomputer

$10^{12}$  devices in  $1 \text{ cm}^2$

$10^{12}$  Hertz switching speed

$\sim 10^4 \text{ Watts!}$

## Nanocomputer\* ~ Pentium III

$10^9$  devices in  $10^{-3} \text{ cm}^2!$

$10^9$  Hertz

$\sim 10^{-2} \text{ Watts}$

\*Assumes  $10^{12}/\text{cm}^2$  device density & 2.5 kT/operation



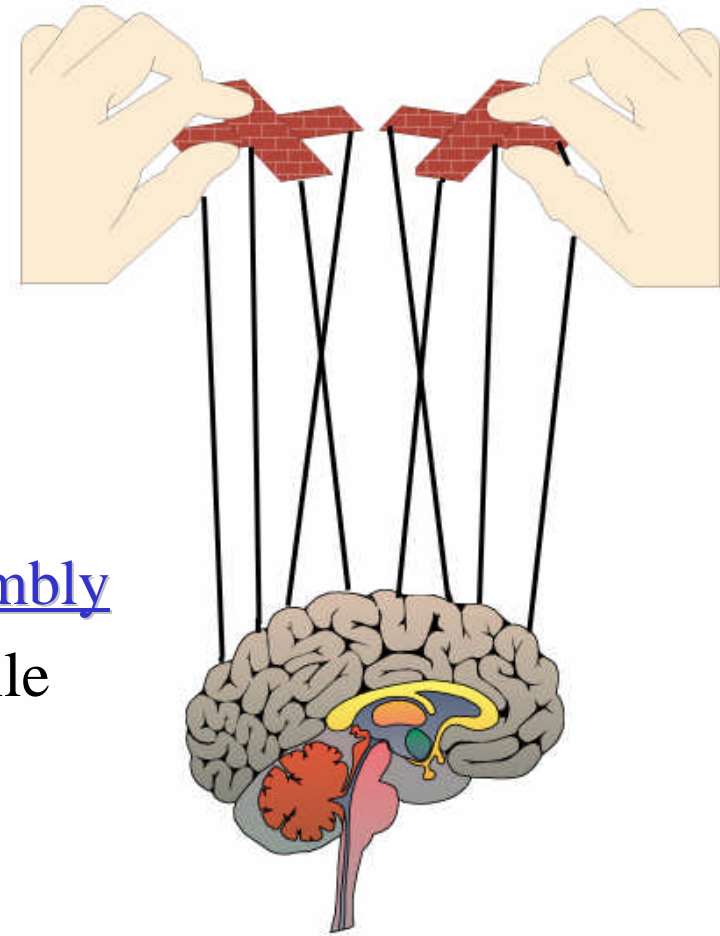
# A Molecular Computer that Needs to be “Taken to School”

## Old Way: Precision Design and Build

Design - Build - Compile

## New Way: Directed Design and Self-Assembly

Build - Measure - Reconfigure - Compile

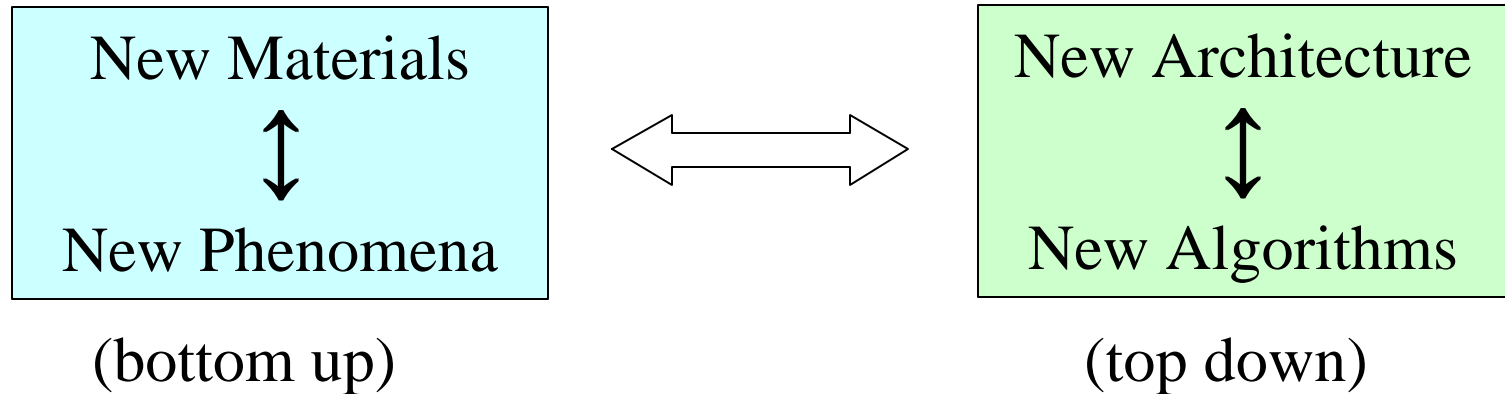


# Comparisons Between Si CMOS and Moletronics

<u>Properties</u>	<u>Si CMOS</u>	<u>Moletronics</u>
Fabrication	Lithography	Hierarchical assembly
Defined properties?	Yes	No
Defects?	No	Yes
Power	Central	Distributed
Approach	Top-down	Bottom-up Top-down



# Conclusions



Molecular/nano materials  
Self-assembly  
Hierarchical assembly

- 
- 
- 

Multi-state systems  
Defect/fault tolerance  
Algorithm development

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- 
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